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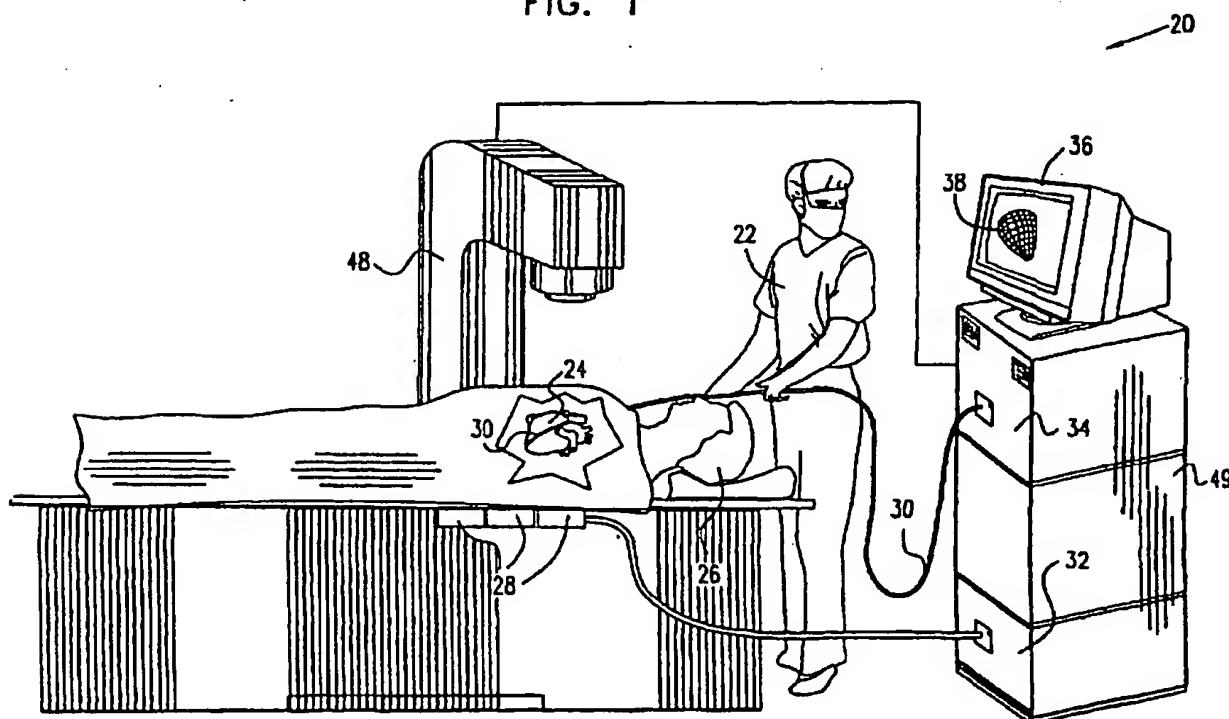
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(54) **Method and apparatus for three-dimensional image rendering of body organs**

(57) A method for mapping a structure in a body of a subject includes capturing a three-dimensional (3D) image of the structure comprising diagnostic information, and generating a 3D geometrical map of the structure using a probe inserted into the structure. The image

is registered with the map, such that each of a plurality of image points in the image is identified with a corresponding map point in the map. The map is displayed such that the diagnostic information associated with each of the image points is displayed at the corresponding map point.

FIG. 1



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Description

FIELD OF THE INVENTION

- 5 [0001] The present invention relates generally to systems and methods for three-dimensional mapping and reconstruction, and specifically to mapping and reconstruction of the interior of body organs, such as the heart.

BACKGROUND OF THE INVENTION

- 10 [0002] Various methods of diagnostic imaging are known in the art. Methods used for imaging the heart, for example, include fluoroscopy, angiography, echocardiography, computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET) and single photon emission tomography (SPECT). Many of these methods produce three-dimensional (3D) image information, which can then be rendered for viewing in the form of parallel slices through the heart, or as a pseudo-3D display on a video monitor. In order to administer treatment, the treating physician
15 must build a 3D picture in his or her mind based on the two-dimensional pictures that are displayed. The transposition is particularly tricky when therapy is to be administered inside the heart, such as local electrical ablation of aberrant electrical pathways, or laser myocardial revascularization.

- [0003] It is also known in the art to map the heart using a mapping probe, typically a catheter, inside the heart chambers. Exemplary methods and devices for this purpose are described in U.S. Patents 5,471,982 and 5,391,199
20 and in PCT patent publications WO94/06349, WO96/05768 and WO97/24981, whose disclosures are incorporated herein by reference. U.S. Patent 5,391,199, for example, describes a catheter that includes both electrodes for sensing cardiac electrical activity and miniature coils for determining the position of the catheter relative to an externally-applied magnetic field. Using this catheter a cardiologist can collect data from a set of sampled points in the heart within a short period of time, by measuring the electrical activity at a plurality of locations and determining the spatial coordinates
25 of the locations. Locations of the mapping catheter within the heart can be superimposed on a 3D reconstruction of an image of the heart, such as an ultrasound image, acquired prior to or during the catheter study. Color codes are used to represent electrical activity sensed by the catheter.

- [0004] U.S. Patent 5,738,096, whose disclosure is incorporated herein by reference, describes methods for geometrical mapping of the endocardium based on bringing a probe into contact with multiple locations on a wall of the heart,
30 and determining position coordinates of the probe at each of the locations. The position coordinates are combined to form a map of at least a portion of the heart. Once the position of the catheter is known, external sensors can be used to provide local physiological values of heart tissue adjacent to the tip of the catheter. For example, if the catheter incorporates a radioactive marker suitable for SPECT, local functional information can be gleaned from a SPECT image. Yet another example is determining local perfusion from Doppler-ultrasound images of the coronaries, from nuclear
35 medicine images or from X-ray or CT angiography, and overlaying the perfusion map on the geometrical map. The image of the catheter in the perfusion map can be used to align the perfusion map and the geometrical map. Alternatively, the alignment may be carried out using fiducial marks or anatomical reference locations, either automatically or manually.

- [0005] Further methods for creating a three-dimensional map of the heart based on these data are disclosed, for
40 example, in European patent application EP 0 974 936 and in EP-A-0 974 936 whose disclosure is incorporated herein by reference. As indicated in these applications, position coordinates (and optionally electrical activity, as well) are initially measured at about 10 to 20 points on the interior surface of the heart. These data points are generally sufficient to generate a preliminary reconstruction or map of the cardiac surface to a satisfactory quality. The preliminary map is preferably combined with data taken at additional points in order to generate a more comprehensive map.

45

SUMMARY OF THE INVENTION

- [0006] It is an object of some aspects of the present invention to provide improved methods and apparatus for mapping and visualization of internal body structures, and particularly of the heart.

- 50 [0007] It is a further object of some aspects of the present invention to provide improved methods and apparatus for administering local treatment of pathological conditions within the heart.

- [0008] In preferred embodiments of the present invention, a position-sensing catheter is used to generate a 3D geometrical map of the internal surface of a heart chamber of a subject. A 3D diagnostic image of the heart is captured in conjunction with generating the 3D map, typically either before or concurrently with the mapping. The image and
55 map are brought into mutual registration, and diagnostic information from the image, such as perfusion information, is then marked on the 3D map, preferably in the form of color coding. Based on the combined diagnostic and geometrical information, a physician operating the catheter is able to identify and visualize areas of the heart that are in need of treatment, due to low perfusion, for example. The physician preferably uses the catheter to apply a local invasive

therapy, such as laser revascularization, to specific points that are located using the color-coded 3D map. Alternatively, a local diagnostic technique, such as a biopsy, may be performed at such specific points.

[0009] There is therefore provided, in accordance with a preferred embodiment of the present invention, a method for mapping a structure in a body of a subject, including:

- 5 capturing a three-dimensional (3D) image of the structure including diagnostic information;
- generating a 3D geometrical map of the structure using a probe inserted into the structure;
- registering the image with the map, such that each of a plurality of image points in the image is identified with a corresponding map point in the map; and
- 10 displaying the map, such that the diagnostic information associated with each of the image points is displayed at the corresponding map point.

[0010] In a preferred embodiment, the diagnostic information is related to blood flow in the structure, wherein the diagnostic information includes local perfusion data. In other preferred embodiments, the diagnostic information includes metabolic data, or is related to uptake of a substance in tissue of the structure, or is related to motion of the structure.

[0011] Preferably, generating the geometrical map includes bringing the probe into contact with the structure at a multiplicity of locations on the structure, and recording position coordinates of the probe at the locations, wherein recording the position coordinates includes determining the coordinates using a position sensor in the probe.

20 [0012] Preferably, registering the image with the map includes applying a transformation to at least one of the image and the map so that following the transformation, the image and the map have a common axis and a common scale. Further preferably, registering the image with the map includes dividing the image into a plurality of parallel planar slices, perpendicular to the axis and mutually spaced along the axis, wherein the plurality of image points are located in the slices. More preferably, registering the image with the map includes finding an axial coordinate of each of the slices and an angular coordinate of each of the image points located in each of the slices, and identifying each of the image points with the map point having the same axial and angular coordinates. Most preferably, the structure includes a wall defining a cavity, and identifying each of the image points with the map point includes finding, at the axial and the angular coordinate, the image point that is within a section of the wall.

[0013] Preferably, displaying the map includes coloring the map to reflect the diagnostic information.

30 [0014] In a preferred embodiment, the method includes performing a medical procedure on the structure guided by the diagnostic information displayed on the map. Preferably, performing the medical procedure includes using the probe to perform the procedure locally at locations selected on the geometrical map, and the method includes marking on the geometrical map the locations at which the procedure was performed. Additionally or alternatively, performing the medical procedure includes performing a therapeutic procedure, wherein the diagnostic information relates to local blood flow in the structure, and wherein performing the therapeutic procedure includes performing a procedure for improving the local blood flow. Alternatively, performing the medical procedure includes performing a diagnostic procedure.

[0015] Preferably, the structure includes a heart of the subject, and generating the geometrical map includes mapping an endocardial surface in a ventricle of the heart.

40 [0016] There is also provided, in accordance with a preferred embodiment of the present invention, apparatus for mapping a structure in a body of a subject, including:

- an imaging device, adapted to capture a three-dimensional (3D) image of the structure including diagnostic information;
- 45 a probe, adapted to be inserted into the structure, so as to generate a 3D geometrical map of the structure;
- a processor, coupled to the probe and to the imaging device, and adapted to register the image with the map, such that each of a plurality of image points in the image is identified with a corresponding map point in the map; and
- a display, coupled to be driven by the processor to display the map, such that the diagnostic information associated with each of the image points is displayed at the corresponding map point.

50 [0017] The present invention will be more fully understood from the following detailed description of the preferred embodiments thereof, taken together with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

55 [0018]

Fig. 1 is a schematic, pictorial illustration of a system for imaging, mapping and treatment of the heart, in accordance

with a preferred embodiment of the present invention;

Fig. 2 is a flow chart that schematically illustrates a method for imaging, mapping and treating the heart, in accordance with a preferred embodiment of the present invention;

Fig. 3 is a schematic representation of a map of a chamber of the heart, in accordance with a preferred embodiment of the present invention;

Fig. 4 is a simplified geometrical representation of the map of Fig. 3, showing coordinates used in registering the map with an image of the heart, in accordance with a preferred embodiment of the present invention;

Fig. 5 is a schematic, exploded view of a 3D image of the heart, represented as a stack of parallel slices through the heart, in accordance with a preferred embodiment of the present invention;

Fig. 6 shows the slices of Fig. 5 arrayed side-by-side, illustrating registration of the slices with the 3D map of Fig. 3, in accordance with a preferred embodiment of the present invention; and

Fig. 7 is a schematic representation of the map of Fig. 3, after coloring of the map with diagnostic information from the image of Figs. 5 and 6, in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0019] Fig. 1 is a schematic, pictorial illustration of a system 20 for three-dimensional geometrical mapping, imaging and treatment of a heart 24 of a subject 26, in accordance with a preferred embodiment of the present invention. System 20 comprises an elongate probe, preferably a catheter 30, which is inserted by a user 22 through a vein or artery of the subject into a chamber of the heart.

[0020] Catheter 30 preferably comprises at least one position sensor (not shown in the figures), most preferably located near the catheter's distal tip. The position sensor preferably comprises an electromagnetic sensor, which is mounted within the catheter by any suitable method, for example, using polyurethane glue or the like. The sensor is electrically connected to an electromagnetic sensor cable, which extends through the catheter body and into a control handle of the catheter. In the control handle, the wires of the sensor cable are connected to a circuit board (not shown), which amplifies the signals received from the electromagnetic sensor and transmits them to a computer housed in a console 34, in a form understandable to the computer. Because the catheter is designed for single use only, the circuit board preferably contains an EPROM chip, which shuts down the circuit board after the catheter has been used. This prevents the catheter, or at least the electromagnetic sensor, from being used twice.

[0021] To use the electromagnetic sensor, subject 26 is placed in a magnetic field generated, for example, by situating under the patient a pad containing field generator coils 28 for generating a magnetic field, driven by driver circuits 32. A reference electromagnetic sensor (not shown) is preferably fixed relative to the patient, e.g., taped to the patient's back, and catheter 30 containing its sensor is advanced into heart 24. The sensor preferably comprises three small coils, which in the magnetic field generate weak electrical signals indicative of their position in the magnetic field. Signals generated by both the fixed reference sensor and by the sensor in the heart are amplified and transmitted to console 34, which analyzes the signals and then displays the results on a monitor 36. By this method, the precise location of the sensor in the catheter relative to the reference sensor can be ascertained and visually displayed. The sensors can also detect displacement of the catheter that is caused by contraction of the heart muscle.

[0022] Suitable electromagnetic sensors for the purposes of the present invention are described, for example, in the above-mentioned U.S. Patent 5,391,199 and PCT patent publication WO 96/05768. A preferred electromagnetic mapping sensor is manufactured by Biosense Ltd. (Tirat Hacarmel, Israel) and marketed under the trade designation NOGA. Some of the mapping features of catheter 30 and system 20 are implemented in the NOGA-STAR catheter marketed by Biosense Webster, Inc., and in the Biosense-NOGA system, also marketed by Biosense Webster, Inc. Further aspects of the design of catheter 30 and of system 20 generally are described in EP-A-1 125 549 which is incorporated herein by reference. Using such sensors, system 20 achieves continuous generation of six dimensions of position and orientation information with respect to catheter 30. Alternatively, the sensors used in catheter 20 may comprise other types of position and/or coordinate sensors, as described, for example, in U.S. Patent 5,391,199, 5,443,489 or 5,515,853, or in PCT publication WO 94/04938 or WO 99/05971, or substantially any other suitable type of position/coordinate sensing device known in the art.

[0023] As noted above, catheter 30 is coupled to console 34, which enables the user to observe and regulate the functions of the catheter. Console 34 includes a processor, preferably a computer with appropriate signal processing circuits (which are typically contained inside a housing of the computer). The processor is coupled to drive display 36.

User 22 brings the distal tip of catheter 30 into contact with multiple points on the endocardial surface of heart 24, and the position coordinates are recorded at each point. The information derived from this analysis is used to reconstruct a three-dimensional geometrical map 38 of the endocardial surface of heart 24.

5 [0024] System 20 also comprises a diagnostic imaging unit 48, such as an echo Doppler unit, SPECT, PET, MRI, CT or other imaging unit known in the art. Unit 48 is used to capture a 3D diagnostic image of heart 24, preferably while user 22 is mapping the heart using catheter 30. Alternatively, the diagnostic image is captured before beginning the mapping, and unit 48 may, in this case, be separate from the other elements of system 20. Diagnostic data from the image captured by unit 48 are superimposed on map 38, using methods described hereinbelow. Depending on the type and configuration of unit 48, a wide range of different diagnostic data may be represented in the image, such as

10 perfusion, metabolic factors, uptake of markers, heart wall motion or thickness, and/or other anatomical or electrical properties, as are known in the art. The image can also be timed to represent different phases in the heart cycle. [0025] Typically, system 20 includes other elements, some of which are not shown in the figures for the sake of simplicity. In the present embodiment, the system preferably includes a laser console 49, which is used in performing direct myocardial revascularization, as described, for example, in PCT patent application PCT/IL97/00011 and in U.S. patent application 09/109,820, which is assigned to the assignee of the present patent application and whose disclosure is incorporated herein by reference. Console 49 injects laser energy into a suitable waveguide (not shown) within catheter 30. The waveguide conveys the energy to the distal tip of the catheter, where it is applied to revascularize areas of the myocardium suffering from low perfusion. Alternatively, the system may include other therapeutic elements, as are known in the art, particularly elements for delivering local treatment in the heart, such as a radio-frequency driver coupled to an ablation electrode on catheter 30; an ultrasound generator coupled to high-power transducer in the catheter, for ultrasonic ablation of the endocardium; or a supply of a therapeutic agent, such as growth factors for angiogenesis, coupled to an injection needle in the catheter. Still further alternatively, the system may include invasive diagnostic elements, such as biopsy forceps that are operated through catheter 30.

20 [0026] Other elements that may be comprised in system 20 are described, for example, in EP-A-0 974 936.

25 [0027] Typically, system 20 includes an ECG monitor (not shown), coupled to receive signals from one or more body surface electrodes, so as to provide an ECG synchronization signal to console 34. As mentioned above, the system preferably also includes a reference position sensor, either on an externally-applied reference patch attached to the exterior of the patient's body, or on an internally-placed catheter, which is inserted into heart 24 and maintained in a fixed position relative to the heart. By comparing the position of catheter 30 to that of the reference catheter, the coordinates of catheter 30 are accurately determined relative to the heart, irrespective of heart motion. Alternatively,

30 any other suitable method may be used to compensate for heart motion. [0028] Fig. 2 is a flow chart that schematically illustrates a method for imaging, mapping and treatment of heart 24 using system 20, in accordance with a preferred embodiment of the present invention. At an imaging step 50, a diagnostic image of heart 24, such as a SPECT image, is captured. Preferably, although not necessarily, the image is captured while catheter 30 is already located inside the heart. The catheter is used to generate geometrical map 38, at a mapping step 52. Suitable mapping techniques for this purpose are described in the above-mentioned U.S. Patent 5,738,096. The above-mentioned European patent application EP 0 974 936 describe accurate methods for creating the map itself based on the data gathered using catheter 30. The image captured at step 50 and the map created at step 52 are then registered one with the other, at a registration step 54.

40 [0029] Figs. 3 and 4 are schematic representations of map 38 generated by system 20 at step 52, illustrating a method used at registration step 54, in accordance with a preferred embodiment of the present invention. Fig. 3 is a wire frame rendition of the map, representing the left ventricle of heart 24. For the purposes of step 54, a longitudinal axis 72 is drawn through the map, passing through an apex 74 of the ventricle. Preferably, the axis and apex are found automatically by console 34. Alternatively or additionally, these or other features of the map are identified manually by user 22.

45 [0030] Fig. 4 is a simplified geometrical representation of a surface 80 of map 38, generated for the purpose of registration with a diagnostic image of heart 24. Surface 80 corresponds to an approximate locus of the endocardium of the heart, as determined from map 38. A coordinate system is defined in which each point 82 on surface 80 is represented by a distance R from apex 74 and an angle α relative to a downward direction 84 (i.e., the direction pointing toward the feet of subject 26).

50 [0031] In order to register the diagnostic image with map 38, axis 72 and apex 74 are identified in the image, as well, and are aligned with the axis and apex of the map. The identification is preferably automatic but may, alternatively or additionally, be carried out or assisted by user 22. Other landmarks and/or fiducial marks in the heart can also be used in performing the alignment. The scale of the image is adjusted so that its dimensions match those of the map as closely as possible. For many types of diagnostic images, such as perfusion maps, the resolution of the diagnostic information is low, so that imprecision of as much as 10 mm in mutual registration can be tolerated. When higher resolution is required, the registration of the diagnostic image with the geometrical map may be improved using methods of automatic registration such as those described in Appendix A. These methods are optional and are not essential to

the present invention.

[0032] Fig. 5 is a schematic, exploded view of a 3D diagnostic image 90 of heart 24, following registration of the 3D image with geometrical map 38, in accordance with a preferred embodiment of the present invention. This view is generated at a bullseye rendition step 56 in the method of Fig. 2. The bullseye rendition of image 90 comprises a stack of parallel slices 92, which are perpendicular to axis 72. The slices are preferably taken at a fixed slice increment one from another along the axis. Each slice shows a section 94 of image 90, at a distance R from apex 74 that is determined by the slice number.

[0033] Fig. 6 shows slices 92 of image 90 arrayed side-by-side, illustrating extraction of diagnostic data from the slices for application to map 38, in accordance with a preferred embodiment of the present invention. Referring, for example, to slice number 5, sectional image 94 comprises three essential parts: an inner region 100, showing the inside of the ventricle; a wall region 102, showing the myocardium; and an outer region 104, external to the heart. The diagnostic information of interest is in region 102. Assuming image 90 to be a SPECT image, showing perfusion in the heart wall, for example, region 102 will typically have the highest value of perfusion.

[0034] At a coloration transfer step 58, the diagnostic information from each slice 92 is transferred to map 38. Each slice has a known value of distance R from apex 74. For each angle α within the slice, point 82 on surface 80 of the map (Fig. 4) is assumed to be the point at that angle that is located radially in the middle of region 102. In the case that image 90 is a perfusion image, point 82 is simply taken to be the point of highest perfusion at the given angle. In other imaging modalities, finding region 102 is, for the most part, similarly straightforward. The value of the diagnostic data at each point 82 is preferably represented as a color applied to the corresponding region of map 38.

[0035] Fig. 7 is a schematic representation of a colored geometrical map 110, as produced at step 58, in accordance with a preferred embodiment of the present invention. Because of the limited ability of a line drawing to convey qualities of a color image, only two different color regions appear on map 110: a well-perfused region 112, and an ischemic region 114. Preferably, the ischemic region has a darker or "cooler" color than the well-perfused region. In actual applications, in which display 36 comprises a color monitor, a broad range of different colors is used in map 110 to describe different levels of perfusion or of other diagnostic qualities.

[0036] Preferably, system 20 is operated by user 22 to carry out an invasive therapeutic procedure, guided by map 110, at a therapeutic step 60. In the present example, laser console 49 is operated to irradiate ischemic region 114 via catheter 30 with high-intensity laser radiation, as described in the above-mentioned PCT patent application PCT/IL97/00011. The laser creates revascularization channels in the myocardium, which are marked by system 20 with spots 116 on map 110. The combination of the imaging, mapping and therapeutic modalities enables the user to concentrate the treatment in the region of heart 24 that is known to need it, and to ensure that the region is fully covered. Other local therapeutic and diagnostic procedures can similarly benefit from the guidance provided by map 110.

[0037] Although preferred embodiments are described hereinabove with reference to heart 24, the principles of the present invention may similarly be applied to imaging, mapping and treatment of other organs and body structures. It will thus be appreciated that the preferred embodiments described above are cited by way of example, and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not disclosed in the prior art.

APPENDIX A

[0038] This appendix provides details of step 54 in the method of Fig. 2, in which two 3D representations, *P* and *Q*, of a chamber of heart 24 are brought into mutual registration. To begin, a rough estimate is found for the transformation between *P* and *Q*, either manually, or using the principle axis of a bounding ellipsoid or by principle component decomposition. The bounding ellipsoid technique is further described in the above-mentioned European patent application EP 0 974 936

[0039] Fine registration between *P* and *Q* is then preferably found using a variation of the Iterative Closest Point (ICP) algorithm. This algorithm is described by Besl and McKay in "A Method for Registration of 3D Shapes," published in *IEEE Transactions on Pattern Analysis and Machine Intelligence* 14(2):239-256 (1992), which is incorporated herein by reference. The following steps are repeated until convergence:

1. Nearest point search: For each point *p* in *P* find the closest point *q* on *Q*. One can take a subset of points of *P* to improve computation speed. Similarly, all points of *Q* can be covered, too, to ensure robustness.
2. Compute registration: Evaluate a transformation *T* that minimizes the sum of squared distances between pairs of closest points (*p*, *q*). The transformation is preferably either rigid, similarity, affine or projective as described below.
3. Transform: Apply the transformation *T* to all points in *P*.

[0040] Given two surfaces, P and Q , and two sets of points, $\{p_i \in P\}_i^n$, $\{q_i \in Q\}_i^n$, step 2 of this algorithm seeks a transformation, T , from a family of transformations (according to the possible families described below) that minimizes the mean square error, ϵ , between the corresponding sets:

$$\epsilon^2 = \frac{1}{n} \sum_{i=1}^n \|q_i - T(p_i)\|^2$$

Affine and Projective Transformations

[0041] For affine transformations, defined as $T(p) = Ap + t$,

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \text{ is a } 3 \times 3 \text{ matrix, and } t = \begin{pmatrix} t_1 \\ t_2 \\ t_3 \end{pmatrix}$$

is a translation vector.
We must minimize

$$\epsilon^2 = \frac{1}{n} \sum_{i=1}^n \|q_i - (Ap_i + t)\|^2. \text{ Denoting } p_i = \begin{pmatrix} x_{i1} \\ x_{i2} \\ x_{i3} \end{pmatrix},$$

and

$$q_i = \begin{pmatrix} y_{i1} \\ y_{i2} \\ y_{i3} \end{pmatrix},$$

we have three systems of equations:

$$\underbrace{\begin{pmatrix} x_{11} & x_{12} & x_{13} & 1 \\ x_{21} & x_{22} & x_{23} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & x_{n3} & 1 \end{pmatrix}}_X \underbrace{\begin{pmatrix} a_{j1} \\ a_{j2} \\ a_{j3} \\ t_j \end{pmatrix}}_{a_j} = \underbrace{\begin{pmatrix} y_{1j} \\ y_{2j} \\ \vdots \\ y_{nj} \end{pmatrix}}_{y_j} \quad j = 1, 2, 3$$

[0042] Let a singular value decomposition of X be $X = UDV^T$. It then follows that $a_j = VDU^T y_j$

[0043] Projective transformations are evaluated in a similar way to the affine case.

Similarity and Rigid Transformation

[0044] Whereas in affine transforms triangles are transformed to triangles, similarity transformations preserve proportions. We seek a scaling factor, c , a 3×3 rotation matrix, R , and a 3-dimensional translation vector, t , such that $T(p) = cRp + t$, wherein the error

$$\epsilon^2(R, T, c) = \frac{1}{n} \sum_{i=1}^n \|q_i - (cRp_i + t)\|^2$$

is minimized.

[0045] A suitable method for finding the desired similarity transform is described by Umeyama, in "Least-Squares Estimation of Transformation Parameters Between Two Point Patterns," published in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 13(4): 376-380 (1991), which is incorporated herein by reference. Define the center of mass of both P and Q :

$$\mu_P = \frac{1}{n} \sum_{i=1}^n p_i$$

$$\mu_Q = \frac{1}{n} \sum_{i=1}^n q_i$$

[0046] Then define the variance of the points on both P and Q :

$$\sigma_P^2 = \frac{1}{n} \sum_{i=1}^n \|p_i - \mu_P\|^2$$

$$\sigma_Q^2 = \frac{1}{n} \sum_{i=1}^n \|q_i - \mu_Q\|^2$$

[0047] The covariance matrix between the two surfaces is

$$\Sigma_{PQ} = \frac{1}{n} \sum_{i=1}^n (q_i - \mu_Q)(p_i - \mu_P)^T$$

[0048] Let a singular value decomposition of Σ_{PQ} be $\Sigma_{PQ} = UDV^T$, and

$$S = \begin{cases} I & \text{if } \det(U)\det(V) = 1 \\ \text{diag}(1,1,-1) & \text{if } \det(U)\det(V) = -1 \end{cases}$$

[0049] The rotation, translation and scaling of the transformation are then given by:

$$R = USV^T$$

$$t = \mu_q - cR\mu_p$$

$$c = \frac{1}{\sigma_p^2} \text{trace}(DS)$$

wherein the trace of a matrix is the sum of its diagonal elements.

[0050] In the case of rigid transformation no scaling is applied, so that $c = 1$.

15 Claims

1. A method for mapping a structure in a body of a subject, comprising:

capturing a three-dimensional (3D) image of the structure comprising diagnostic information;
generating a 3D geometrical map of the structure using a probe inserted into the structure;
registering the image with the map, such that each of a plurality of image points in the image is identified with
a corresponding map point in the map; and
displaying the map, such that the diagnostic information associated with each of the image points is displayed
at the corresponding map point.

2. A method according to claim 1, wherein the diagnostic information:

is related to blood flow in the structure;
comprises local perfusion data;
comprises metabolic data;
is related to uptake of a substance in tissue of the structure; or
is related to motion of the structure.

3. The method of claim 1 or claim 2 wherein generating the geometrical map comprises bringing the probe into contact
with the structure at a multiplicity of locations on the structure, and recording position coordinates of the probe at
the locations.

4. The method of claim 3, wherein recording the position coordinates comprises determining the coordinates using
a position sensor in the probe.

5. The method of any one of claims 1 to 4, wherein registering the image with the map comprises applying a trans-
formation to at least one of the image and the map so that, following the transformation, the image and the map
have a common axis and a common scale.

6. The method of claim 5, wherein registering the image with the map comprises dividing the image into a plurality
of parallel planar slices, perpendicular to the axis and mutually spaced along the axis, and wherein the plurality of
image points are located in the slices.

7. The method of claim 6, wherein registering the image with the map comprises finding an axial coordinate of each
of the slices and an angular coordinate of each of the image points located in each of the slices, and identifying
each of the image points with the map point having the same axial and angular coordinates.

8. The method of claim 7, wherein the structure comprises a wall defining a cavity, and wherein identifying each of
the image points with the map point comprises finding, at the axial and the angular coordinate, the image point
that is within a section of the wall.

9. The method of any one of claims 1 to 8, wherein displaying the map comprises coloring the map to reflect the
diagnostic information.

10. The method of any one of claims 1 to 9, wherein the structure comprises a heart of the subject, and wherein generating the geometrical map comprises mapping an endocardial surface in a ventricle of the heart.
11. Apparatus for mapping a structure in a body of a subject, comprising:
 - an imaging device, adapted to capture a three-dimensional (3D) image of the structure comprising diagnostic information;
 - a probe, adapted to be inserted into the structure, so as to generate a 3D geometrical map of the structure;
 - a processor, coupled to the probe and the imaging device, and adapted to register the image with the map, such that each of a plurality of image points in the image is identified with a corresponding map point in the map; and
 - a display, coupled to be driven by the processor to display the map, such that the diagnostic information associated with each of the image points is displayed at the corresponding map point.
12. Apparatus of claim 11, wherein the diagnostic information:
 - is related to blood flow in the structure;
 - comprises local perfusion data;
 - comprises metabolic data;
 - is related to uptake of a substance in tissue of the structure; or
 - is related to motion of the structure.
13. Apparatus of claim 11 or claim 12, wherein, to generate the geometrical map, the probe is adapted to be brought into contact with the structure at a multiplicity of locations on the structure, and the processor is adapted to record position coordinates of the probe at the locations.
14. Apparatus of claim 13, wherein the probe comprises a position sensor for use in determining the position coordinates.
15. Apparatus of any one of claims 11 to 13, wherein the processor is adapted to register the image with the map by applying a transformation to at least one of the image and the map so that following the transformation, the image and the map have a common axis and a common scale.
16. Apparatus of claim 15, wherein the processor is further adapted to divide the image into a plurality of parallel planar slices, perpendicular to the axis and mutually spaced along the axis, wherein the plurality of image points are located in the slices.
17. Apparatus of claim 16, wherein the processor is adapted to find an axial coordinate of each of the slices and an angular coordinate of each of the image points located in each of the slices, and to identify each of the image points with the map point having the same axial and angular coordinates.
18. Apparatus of claim 17, wherein, when the structure comprises a wall defining a cavity, the processor is adapted to identify each of the image points with the map point by finding, at the axial and the angular coordinate, the image point that is within a section of the wall.
19. Apparatus of any one of claims 11 to 18, which is adapted to provide a map colored to reflect the diagnostic information.
20. Apparatus of any one of claims 11 to 19, wherein the structure comprises a heart of the subject, and wherein the geometrical map comprises a map of an endocardial surface in a ventricle of the heart.
21. Apparatus of any one of claims 11 to 20, and comprising a medical instrument adapted to perform a medical procedure on the structure guided by the diagnostic information displayed on the map.
22. Apparatus of claim 21, wherein the medical instrument is contained in the probe, which is adapted to be used to perform the procedure locally at locations selected on the geometrical map.
23. Apparatus of claim 22, wherein the processor is adapted to mark on the geometrical map the locations at which

the procedure was performed.

24. Apparatus of any one of claims 21 to 23 for carrying out therapeutic procedure.

5 25. Apparatus of claim 24, wherein the diagnostic information relates to local blood flow in the structure, for carrying out a therapeutic procedure for improving the local blood flow.

26. Apparatus of any one of claims 21 to 23 for carrying out a diagnostic procedure.

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FIG. 1

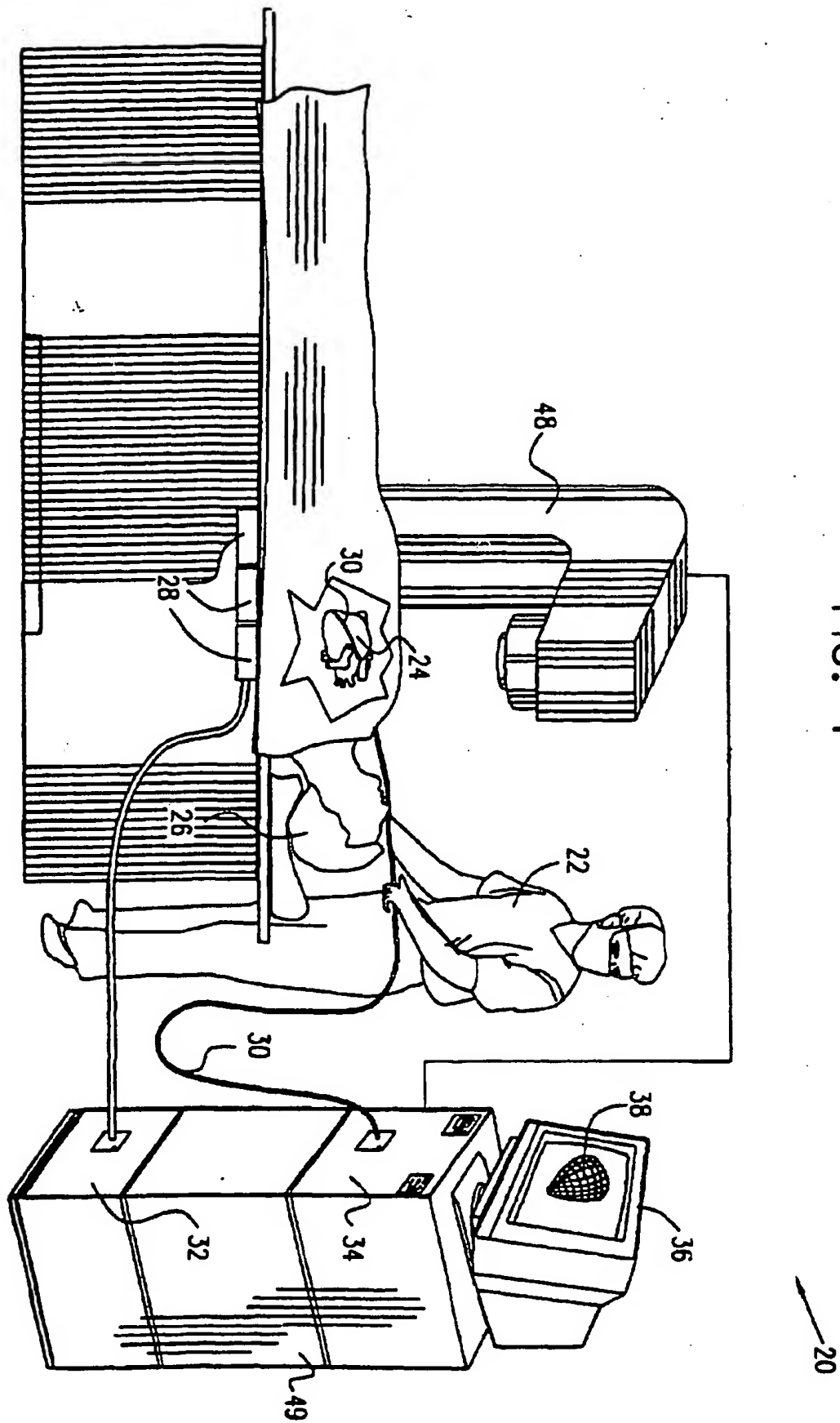
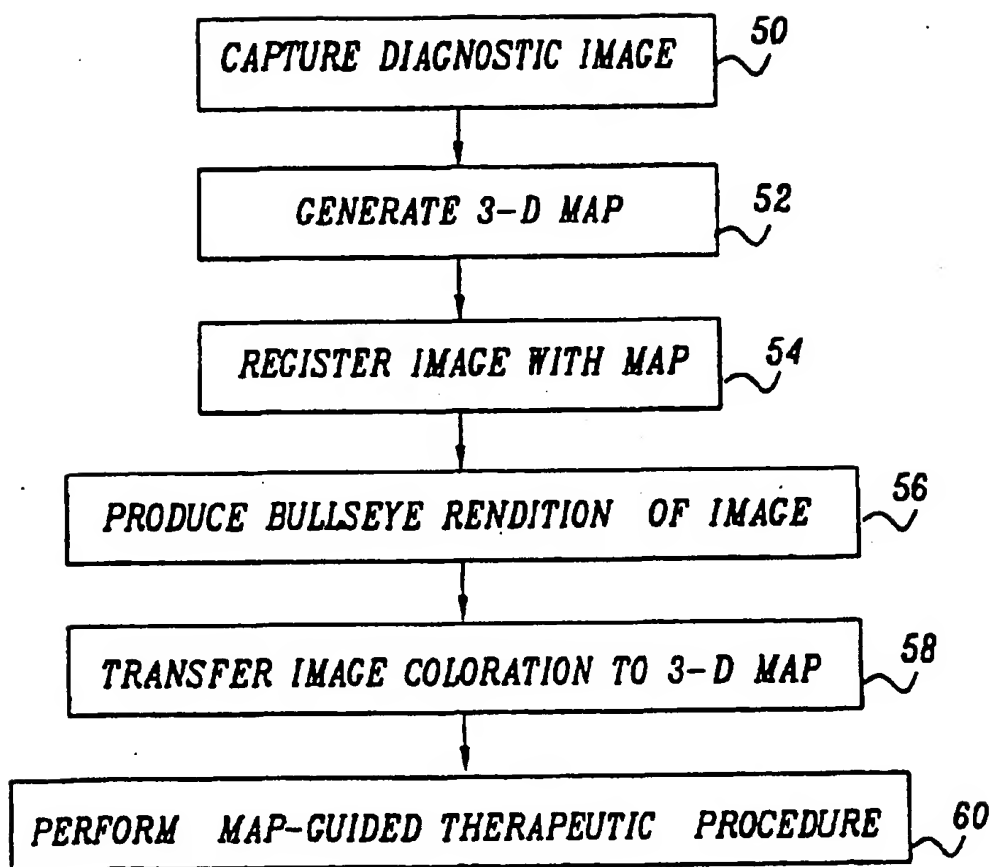


FIG. 2



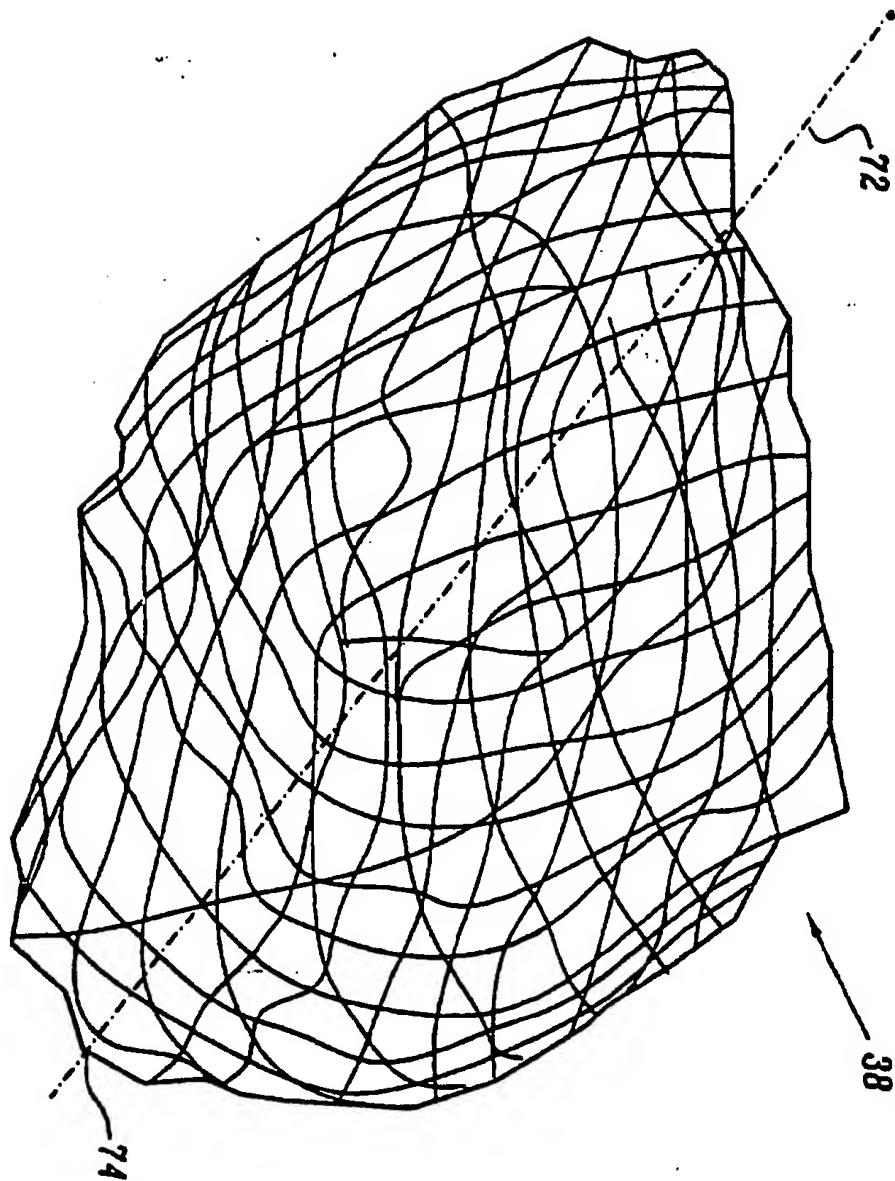


FIG. 3

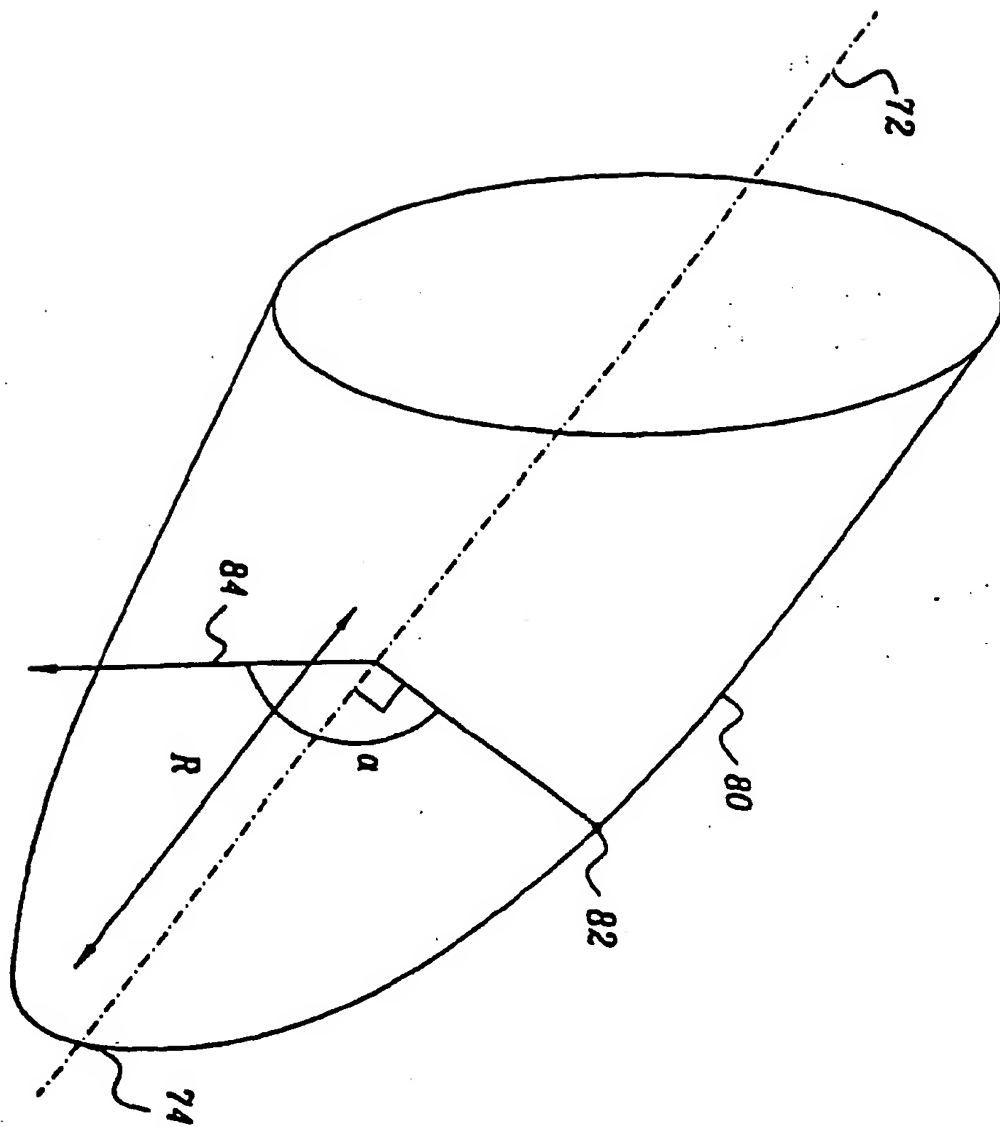
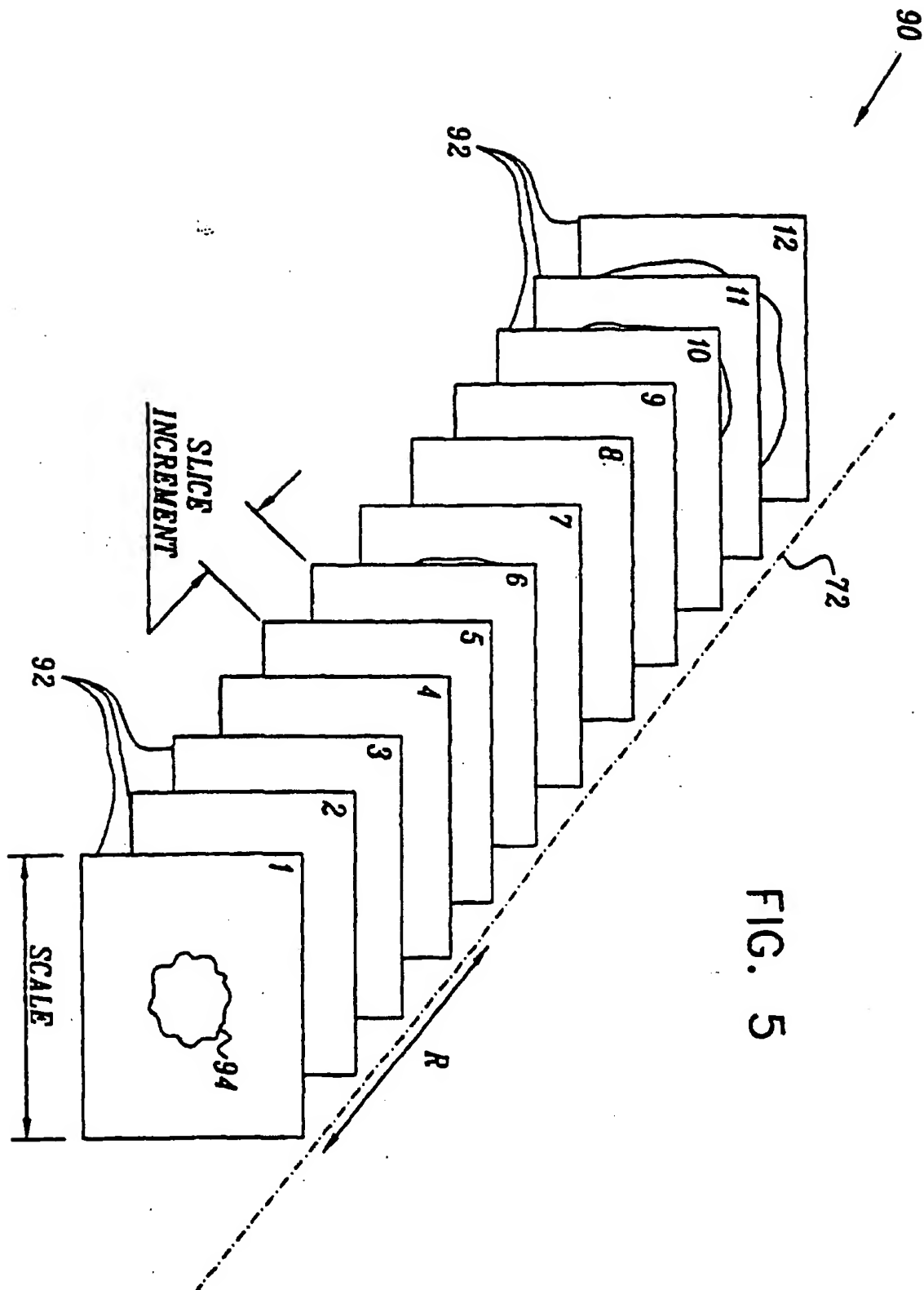


FIG. 4



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FIG. 6

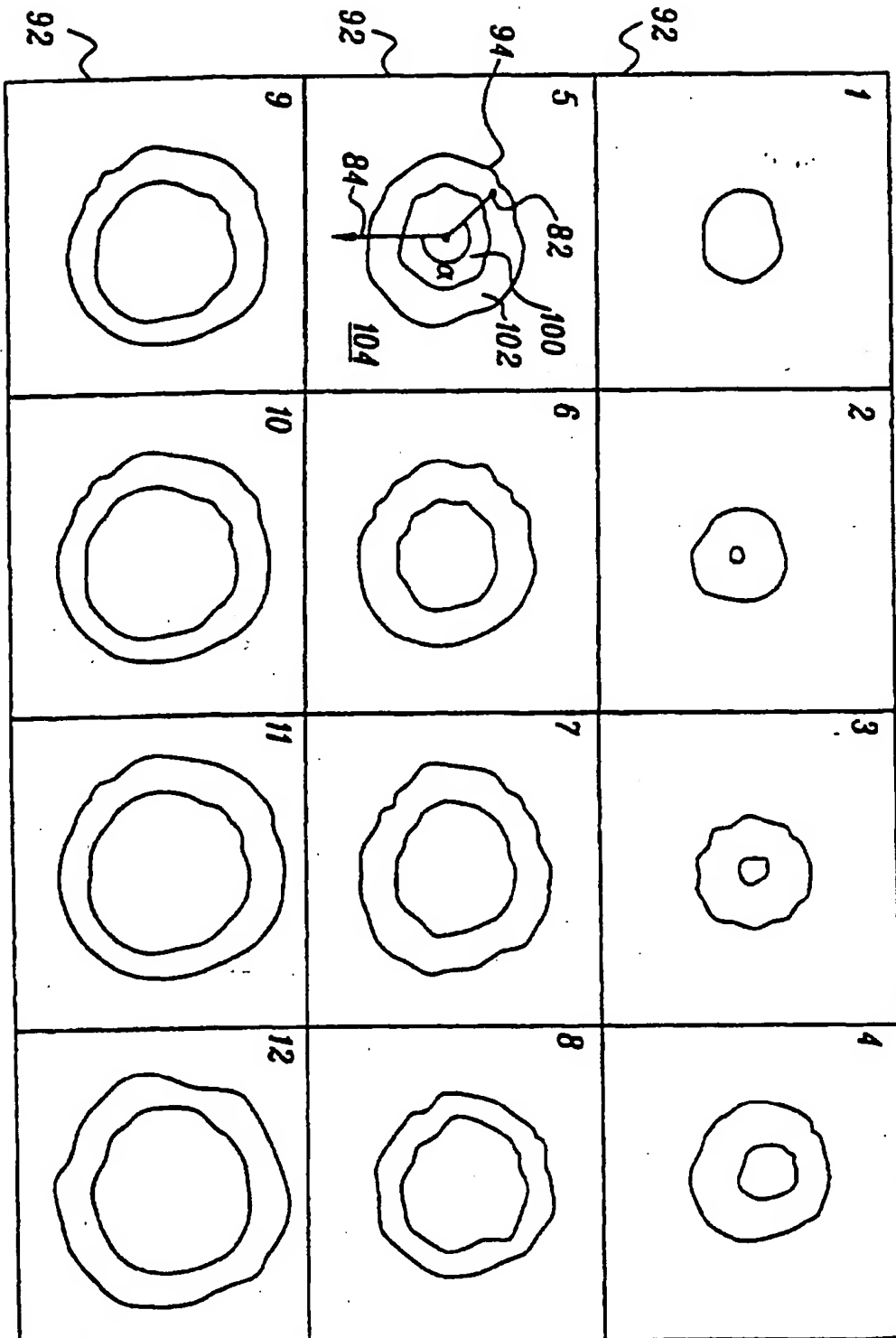
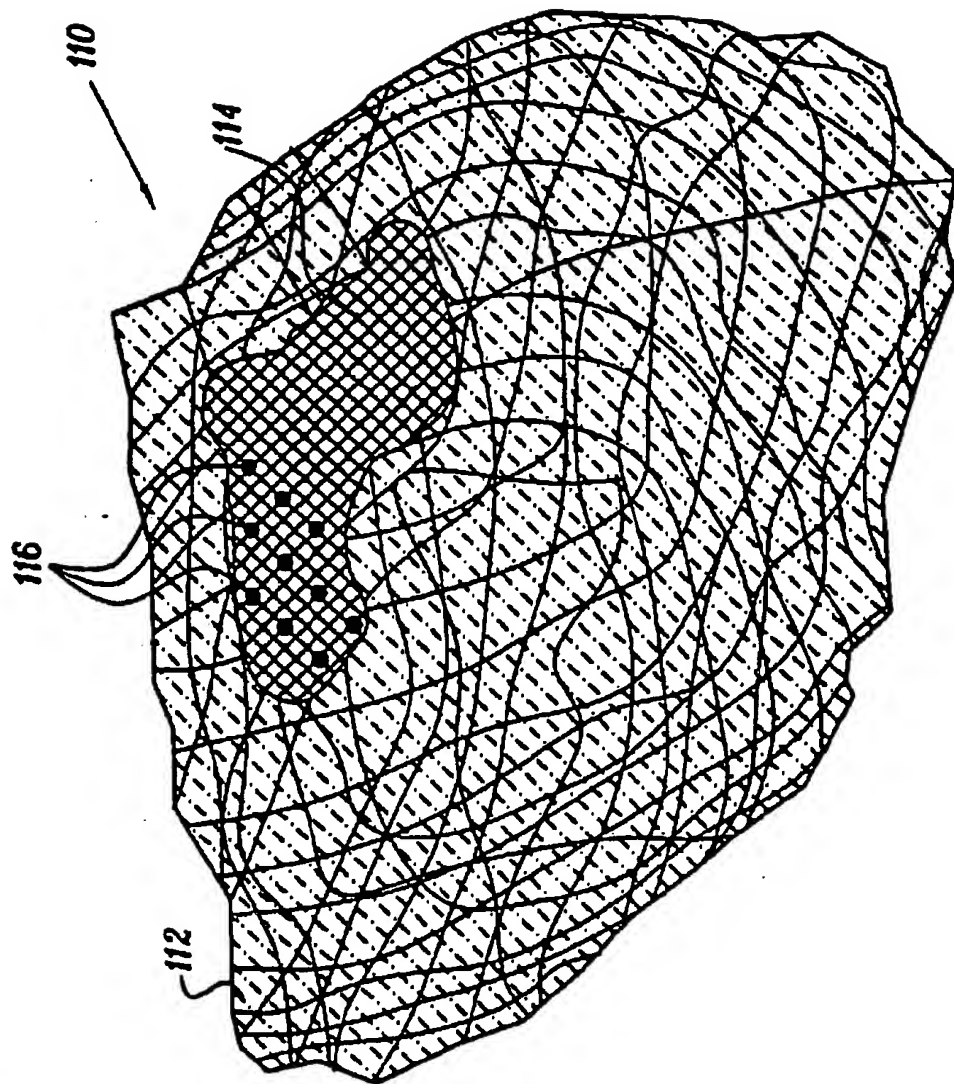
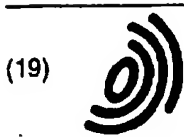


FIG. 7





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(11)

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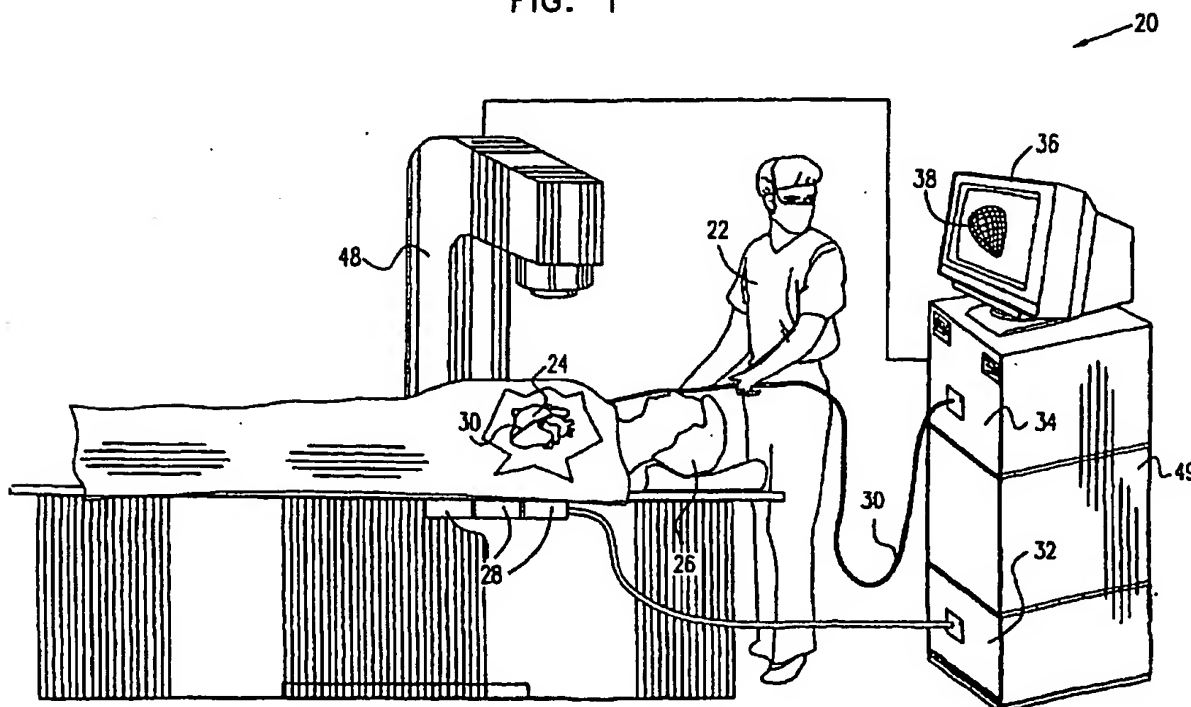
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(54) Method and apparatus for three-dimensional image rendering of body organs

(57) A method for mapping a structure in a body of a subject includes capturing a three-dimensional (3D) image of the structure comprising diagnostic information, and generating a 3D geometrical map of the structure using a probe inserted into the structure. The image

is registered with the map, such that each of a plurality of image points in the image is identified with a corresponding map point in the map. The map is displayed such that the diagnostic information associated with each of the image points is displayed at the corresponding map point.

FIG. 1



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EUROPEAN SEARCH REPORT

Application Number
EP 01 30 7001

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	SCHILLING ET AL: "Mapping and ablation of ventricular tachycardia with the aid of a non-contact mapping system" HEART, vol. 81, no. 6, June 1999 (1999-06), pages 570-575, XP002284986 * page 571, column 2, lines 26-31; page 572, column 1, lines 5-25 * * page 572, column 1, lines 21-24 * * figure 2 *	1,11	G06T17/00
X		9,19	
X		10,20	
D,X	US 5 738 096 A (BEN-HAIM SHLOMO) 14 April 1998 (1998-04-14) * column 9, line 5 - line 10 *	3,4,13, 14	
A	J B A MAINTZ, M A VIERGEVER: "A Survey of Medical Image Registration" MEDICAL IMAGE ANALYSIS, vol. 2, no. 1, March 1998 (1998-03), pages 1-36, XP002284987 * page 1, column 2, lines 14-16; page 6, column 2, lines 17-26 *	5,15	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
A	T L FABER ET AL: "Three-Dimensional Displays of Left Ventricular Epicardial Surface from Standard Cardiac SPECT Perfusion Quantification Techniques" JOURNAL OF NUCLEAR MEDICINE, vol. 36, no. 4, April 1995 (1995-04), pages 697-703, XP008031998 * page 698 *	6-8, 16-18	G06T A61B
D,A	EP 0 974 936 A (BIOSENSE INC) 26 January 2000 (2000-01-26) * page 9, lines 39-40 *	21,24,26	
	-/--		
The present search report has been drawn up for all claims			
Place of search: The Hague		Date of completion of the search 25 June 2004	Examiner Reise, F
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document</p> <p>T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons B: member of the same patent family, corresponding document</p>			

EPO FORM 1500 (3.02) (9/94C01)



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 30 7001

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (In I.C.I.7)
A	US 5 769 843 A (ABELA GEORGE S ET AL) 23 June 1998 (1998-06-23) * abstract *	24,25	
A	H YAMAGATA ET AL: "Development of a new display method for compound 3D ultrasound images: Fusion 3D images from B-mode and 3D doppler images" MEDICAL REVIEW, no. 70, 1999, pages 43-46, XP002284988 * abstract *	2	
A	J L BOXERMAN, T J MOSHER, E R MCVEIGH, E ATALAR, J A LIMA, D A BLUMKE: "Advanced MR imaging techniques for evaluation of the heart and great vessels" RADIOGRAPHICS, vol. 18, no. 3, 1988, pages 543-564, XP002284989 * abstract *	2	
A	GULLBERG G T ET AL: "Imaging the mechanical, electrical, and physiological properties of the heart" ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY, 1998. PROCEEDINGS OF THE 20TH ANNUAL INTERNATIONAL CONFERENCE OF THE IEEE HONG KONG, CHINA 29 OCT.-1 NOV. 1998, PISCATAWAY, NJ, USA, IEEE, US, 29 October 1998 (1998-10-29), pages 496-501, XP010320050 ISBN: 0-7803-5164-9 * page 496, column 2, lines 22-30 * ----- -/--	2	
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 25 June 2004	Examiner Reise, F
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 30 7001

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	<p>GILARDI M C ET AL: "Correlation of SPECT and PET cardiac images by a surface matching registration technique" COMPUT. MED. IMAGING GRAPH. (UK), COMPUTERIZED MEDICAL IMAGING AND GRAPHICS, SEPT.-OCT. 1998, ELSEVIER, UK, vol. 22, no. 5, 1988, pages 391-398, XP002284990 ISSN: 0895-6111 * page 391, column 1, lines 1-4 *</p> <p>-----</p>	2	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
The Hague		25 June 2004	Reise, F
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons</p> <p>& : member of the same patent family, corresponding document</p>			

EPO FORM 1503 (03.82) (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 01 30 7001

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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25-06-2004

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5738096 A	14-04-1998	US 5546951 A	20-08-1996
		US 5391199 A	21-02-1995
		AU 715925 B2	10-02-2000
		AU 1170197 A	01-08-1997
		AU 710236 B2	16-09-1999
		AU 1170297 A	01-08-1997
		AU 712539 B2	11-11-1999
		AU 1206697 A	01-08-1997
		AU 724404 B2	21-09-2000
		AU 1206797 A	01-08-1997
		CA 2240943 A1	17-07-1997
		CA 2242353 A1	17-07-1997
		CA 2242356 A1	17-07-1997
		CA 2242360 A1	17-07-1997
		CN 1211930 A	24-03-1999
		DE 69726599 D1	15-01-2004
		DE 69728257 D1	29-04-2004
		EP 1382293 A2	21-01-2004
		EP 1428472 A2	16-06-2004
		EP 0888082 A1	07-01-1999
		EP 0944350 A1	29-09-1999
		EP 0888150 A1	07-01-1999
		EP 0910429 A1	28-04-1999
		WO 9724983 A2	17-07-1997
		WO 9724981 A2	17-07-1997
		WO 9725101 A2	17-07-1997
		WO 9725098 A1	17-07-1997
		WO 9937208 A1	29-07-1999
		IL 125136 A	31-07-2003
		IL 125259 A	01-12-2002
		IL 125260 A	24-06-2003
		US 6066094 A	23-05-2000
		US 6317631 B1	13-11-2001
		US 6285898 B1	04-09-2001
		US 2003139668 A1	24-07-2003
		US 6498944 B1	24-12-2002
		US 2003191383 A1	09-10-2003
		US 6363279 B1	26-03-2002
		US 6330476 B1	11-12-2001
		US 2002045809 A1	18-04-2002
		US 2002045812 A1	18-04-2002
		AT 188108 T	15-01-2000
		AT 253864 T	15-11-2003
		AU 1693095 A	14-03-1996
		CA 2197986 A1	29-02-1996
		CN 1168625 A	24-12-1997

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 01 30 7001

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

25-06-2004

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5738096 A		DE 69514238 D1	03-02-2000
		DE 69514238 T2	11-05-2000
EP 0974936 A	26-01-2000	US 6226542 B1	01-05-2001
		CA 2278380 A1	24-01-2000
		EP 0974936 A2	26-01-2000
		US 6301496 B1	09-10-2001
		US 2001009974 A1	26-07-2001
US 5769843 A	23-06-1998	CA 2247505 A1	21-08-1997
		EP 0901399 A1	17-03-1999
		JP 2001509038 T	10-07-2001
		WO 9729803 A1	21-08-1997

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82



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(12) Patent Application Publication
Okerlund et al.

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(43) Pub. Date: Oct. 2, 2003

(54) METHOD, SYSTEM AND COMPUTER
PRODUCT FOR CARDIAC
INTERVENTIONAL PROCEDURE
PLANNING

Publication Classification

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(52) U.S. Cl. 600/443; 128/916

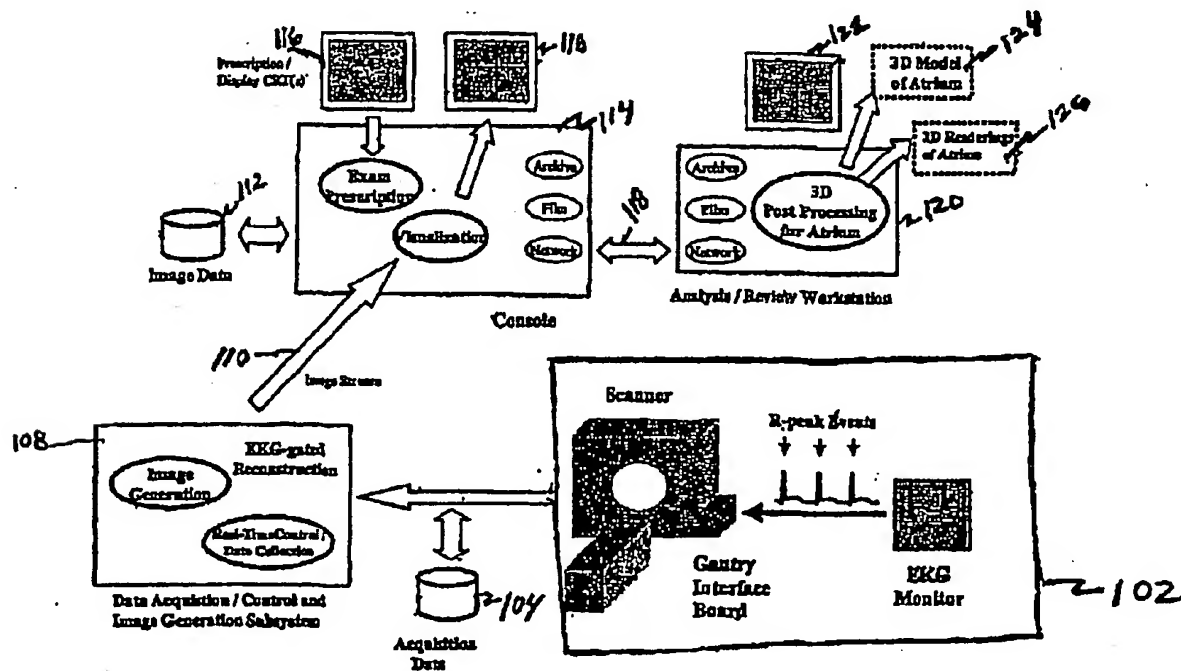
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(21) Appl. No.: 10/063,064

(22) Filed: Mar. 15, 2002

(57) ABSTRACT

A method of creating 3D models to be used for cardiac interventional procedure planning. Acquisition data is obtained from a medical imaging system and cardiac image data is created in response to the acquisition data. A 3D model is created in response to the cardiac image data and three anatomical landmarks are identified on the 3D model. The 3D model is sent to an interventional system where the 3D model is in a format that can be imported and registered with the interventional system.



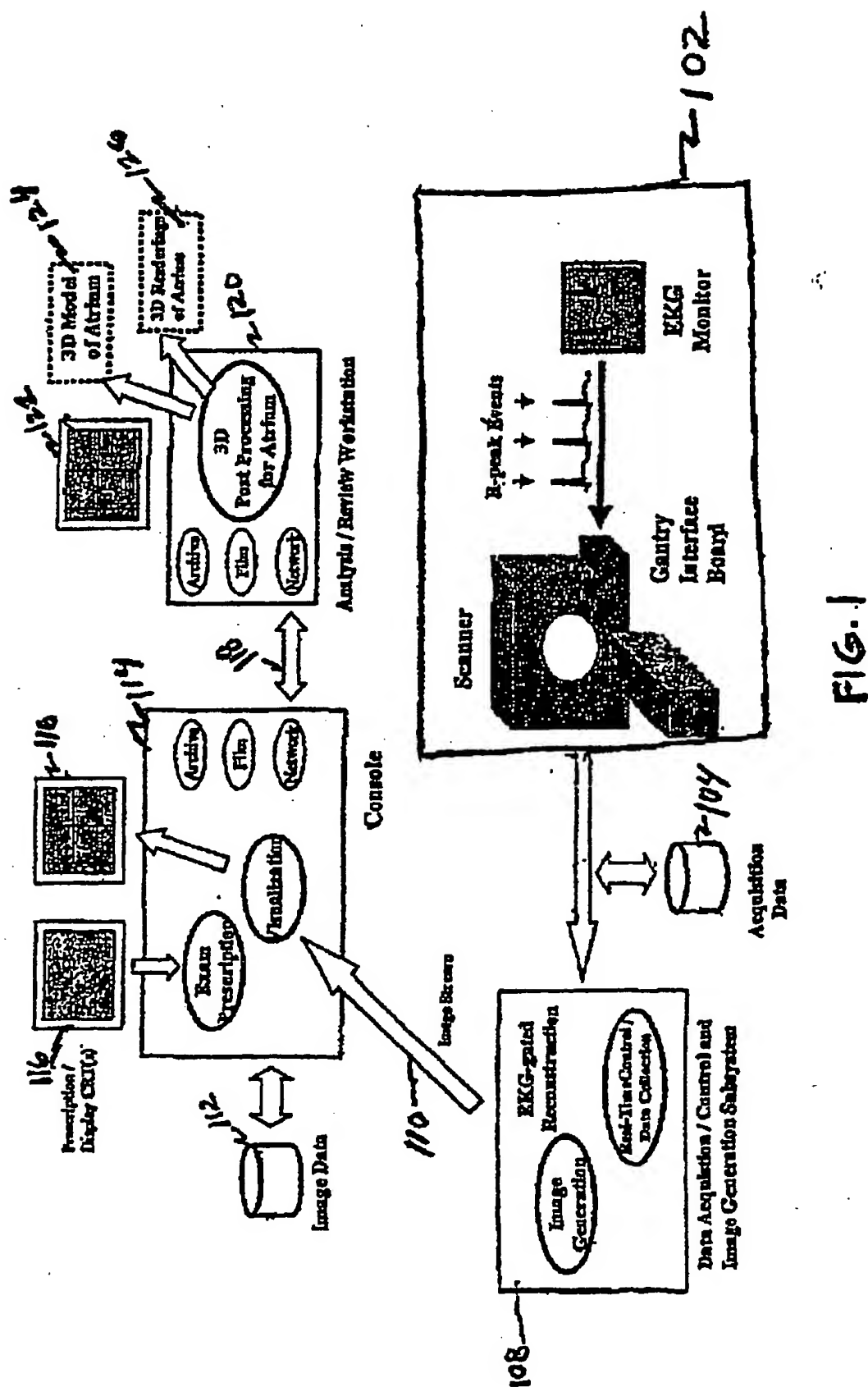


FIG. 1

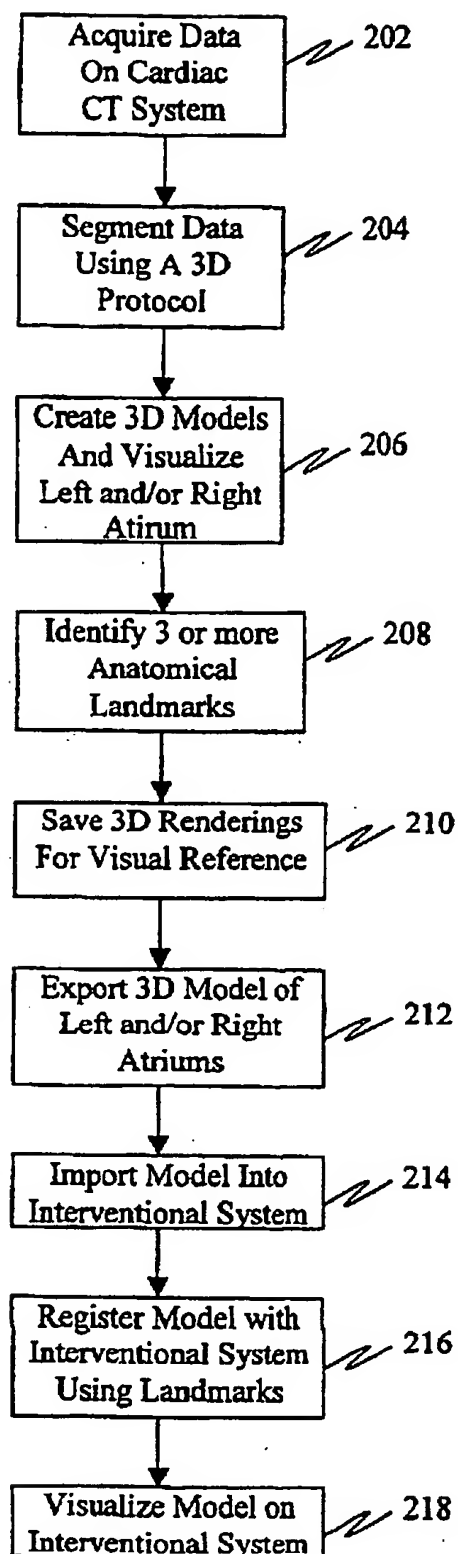


FIG.2

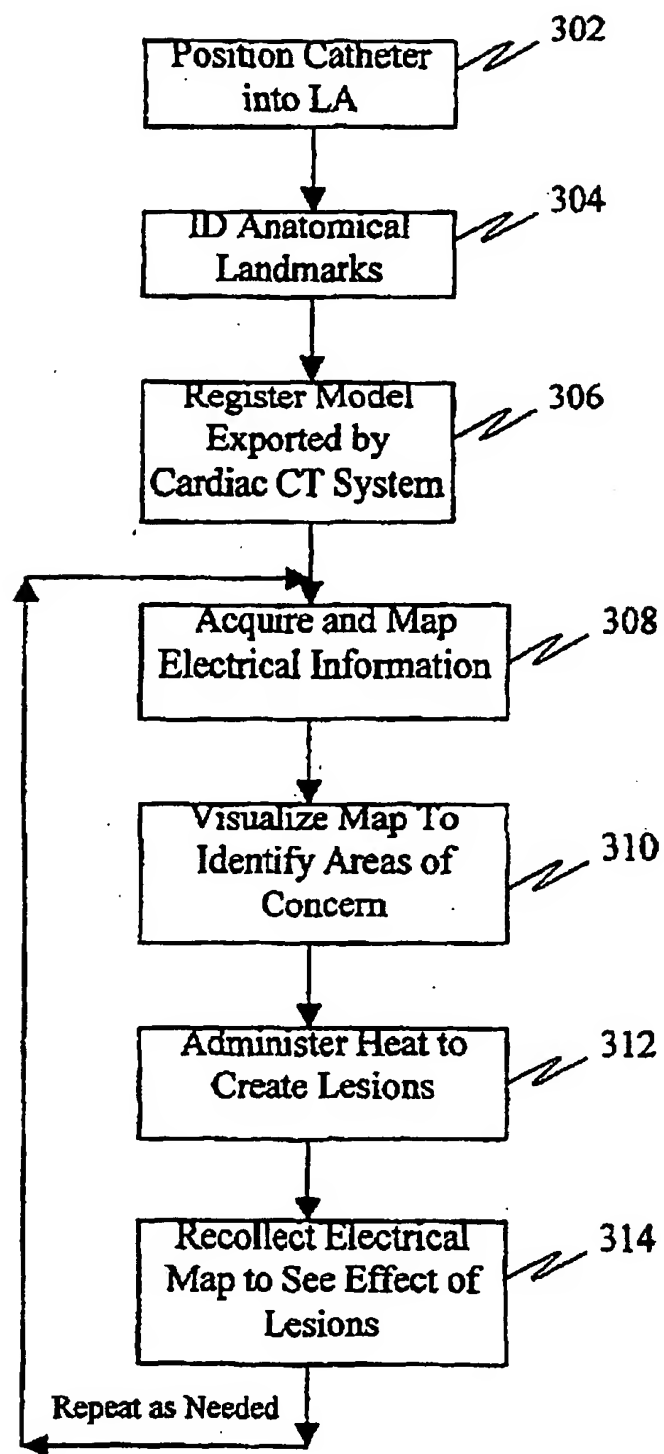


FIG.3

METHOD, SYSTEM AND COMPUTER PRODUCT FOR CARDIAC INTERVENTIONAL PROCEDURE PLANNING

BACKGROUND OF INVENTION

[0001] The present disclosure relates generally to a method for the planning of cardiac interventional procedures and in particular, to a method for using data created by a medical imaging system in cardiac interventional procedure planning.

[0002] Medical diagnostic and imaging systems are ubiquitous in modern health care facilities. Such systems provide invaluable tools for identifying, diagnosing and treating physical conditions and greatly reduce the need for surgical diagnostic intervention. In many instances, final diagnosis and treatment proceed only after an attending physician or radiologist has complemented conventional examinations with detailed images of relevant areas and tissues via one or more imaging modalities.

[0003] Currently, a number of modalities exist for medical diagnostic and imaging systems. These include computed tomography (CT) systems, x-ray systems (including both conventional and digital or digitized imaging systems), magnetic resonance (MR) systems, positron emission tomography (PET) systems, ultrasound systems and nuclear medicine systems. In many instances, these modalities complement one another and offer the physician a range of techniques for imaging particular types of tissue, organs, physiological systems, and so forth. Health care institutions often dispose of several such imaging systems at a single or multiple facilities, permitting its physicians to draw upon such resources as required particular patient needs.

[0004] Modern medical diagnostic systems typically include circuitry for acquiring image data and for transforming the data into a useable form which is then processed to create a reconstructed image of features of interest within the patient. The image data acquisition and processing circuitry is often referred to as a "scanner" regardless of the modality, because some sort of physical or electronic scanning often occurs in the imaging process. The particular components of the system and related circuitry, of course, differ greatly between modalities due to their different physics and data processing requirements.

[0005] Medical diagnosis and treatment can also be performed by using an interventional procedure such as atrial fibrillation (AF) intervention. Approximately 2.2 million people in the United States have AF. It is the most common arrhythmia and is the most troublesome. It is currently the number one independent cause of stroke in the United States. The incidences of AF increase with age, rapidly increasing after the age of sixty. In the case of left atrial fibrillation, muscle tissues around any of the four pulmonary veins (PV) which connect to the left atrium (LA) can sometimes generate an extra electrical signal causing AF. One current clinical treatment for this condition is ablation using a special catheter which is positioned into the left atrium to create small lesions by administering heat near the origin of the problematic electrical signal. Ablation therapy is done routinely during open heart surgery in less than one hour, but it is very difficult and timely using the less invasive catheter procedure.

[0006] In the example of ablation therapy, the following procedure is typical. First, a catheter is positioned into the LA, guided by X-ray fluoro, this takes approximately one hour. Next, a crude 3D geometric representation of the LA and PV ostiums (openings) is acquired using 3D positioning information from a special catheter by attempting to "sweep through" the space of the LA. Acquiring a crude 3D geometric representation typically takes about one hour. The next steps are performed in the following order as many times as necessary. A special catheter is used to acquire electrical information from one or more heart cycles and this electrical information is mapped onto the crude 3D geometric representation using interventional system software. The next step is to visualize this map in order to identify the areas of concern which should be treated with ablation. Heat is then administered to create lesions, as the software keeps track of these locations. The last step is to recollect the electrical map to see the effects of the lesions. If necessary to complete the ablation therapy, the process continues with repeating the previous steps starting with using a special catheter to acquire electrical information. The ablation therapy procedure is lengthy and labor intensive.

SUMMARY OF INVENTION

[0007] One aspect of the invention is a method of creating 3D models to be used for cardiac interventional procedure planning. Acquisition data is obtained from a medical imaging system and cardiac image data is created in response to the acquisition data. A 3D model is created in response to the cardiac image data and three anatomical landmarks are identified on the 3D model. The 3D model is sent to an interventional system where the 3D model is in a format that can be imported and registered with the interventional system.

[0008] Another aspect of the invention is a method for creating 3D models to be used for cardiac interventional procedure planning. Acquisition data is received from a medical imaging system. Cardiac image data is created in response to the acquisition data and a 3D model is created in response to the cardiac image data. Three anatomical landmarks are identified on the 3D model. The 3D model is registered on the interventional system in response to the three anatomical landmarks and the 3D model is visualized on the interventional system.

[0009] A further aspect of the invention is a system for creating 3D models to be used for cardiac interventional procedure planning. The system comprises a medical imaging system, an acquisition database in communication with the medical imaging system, an image database, a data transfer mechanism and a processing device. The processing device is in communication with the data transfer mechanism, the acquisition database and the image database. The processing device includes instructions to create 3D models to be used for cardiac interventional procedure planning. The instructions carry out a method to obtain acquisition data from the medical imaging system where the acquisition data is stored in the acquisition database. Cardiac image data is created in response to the acquisition data where the cardiac image data is stored in the image database. A 3D model is created in response to the cardiac image data and three anatomical landmarks are identified on the 3D model. The 3D model is sent to an interventional system, where the 3D model is in a format that can be registered and imported

into the interventional system. The sending is performed using the data transfer mechanism.

[0010] Another aspect of the invention is a system for creating 3D models to be used for cardiac interventional procedure planning. The system comprises a medical imaging system, an acquisition database in communication with the medical imaging system, an image database, a data transfer mechanism, an interventional system in communication with the data transfer mechanism and a processing device. The processing device is in communication with the data transfer mechanism, the acquisition database and the image database. The processing device includes instructions to create 3D models to be used for cardiac interventional procedure planning. The instructions carry out a method to obtain acquisition data from the medical imaging system where the acquisition data is stored in the acquisition database. Cardiac image data is created in response to the acquisition data where the cardiac image data is stored in the image database. A 3D model is created in response to the cardiac image data and three anatomical landmarks are identified on the 3D model. The 3D model is sent to an interventional system, where the 3D model is in a format that can be registered and imported into the interventional system. The sending is performed using the data transfer mechanism. The 3D model is received at the interventional system and registered in response to the three anatomical landmarks. The 3D model is visualized on the interventional system.

[0011] Another aspect of the invention is a computer program product for creating 3D models to be used for cardiac interventional procedure planning. The product includes a storage medium that is readable by a processing circuit and stores instructions for execution by the processing circuit. The instructions for execution include obtaining acquisition data from a medical imaging system and creating cardiac image data in response to the acquisition data. A 3D model is created in response to the cardiac image data and three anatomical landmarks are identified on the 3D model. The 3D model is sent to an interventional system where the 3D model is in a format that can be imported and registered with the interventional system.

[0012] Further aspects of the invention are disclosed herein. The above discussed and other features and advantages of the present invention will be appreciated and understood by those skilled in the art from the following detailed description and drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0013] Referring to the exemplary drawings wherein like elements are numbered alike in the several Figures:

[0014] FIG. 1 is an overview of a cardiac computed tomography (CT) system with support for cardiac imaging;

[0015] FIG. 2 is a flow diagram of a process where image data created on a cardiac CT is used by an interventional planning system; and

[0016] FIG. 3 is a flow diagram of a revised process for performing an interventional procedure.

DETAILED DESCRIPTION

[0017] FIG. 1 is an overview of an exemplary cardiac computed tomography (CT) system with support for cardiac

imaging. The cardiac CT system is used as an example; other imaging systems known in the art can also be used in an embodiment of the present invention. The scanner portion of the system 102 includes an EKG monitor that outputs Revents into the scanner through a scanner interface board. The scanner interface board can be used to couple the EKG system to the scanner. An example of a scanner interface board is a Gantry interface board. The cardiac CT subsystem 102 includes EKG gated acquisition or image reconstruction capabilities to image the heart free of motion in its diastolic phase. Data is output from the scanner into a subsystem 108 that includes software to perform data acquisition, data control and image generation. In addition, data that is output from the scanner, including R-peak time stamps, is stored in the acquisition database 104. Acquisition is performed according to one or more acquisition protocols that are optimized for imaging the heart and specifically the left and/or right atrium. Image generation is performed using one or more optimized 3D protocols for automated image segmentation of the CT image dataset for the inner surface of the left and/or right atrium.

[0018] Referring to FIG. 1, the image data stream 110 is sent to the operator console 114. The data used by software at the operator console 114 for exam prescription and visualization is stored in an image database 112 along with the data from the image data stream 110. Display screens 116 are provided to the operator of the exam prescription and visualization process. The image data may be archived, put on film or sent over a network to a workstation 120 for analysis and review including 3D post processing. The post processing software depicted in the workstation 120 provides immersible views of the atriums (or ventricle chambers), such that the pulmonary veins can be visualized from the inside of the left atrium, for example. These special views can be saved into a 3D rendering of atrium file 126 and viewed by the interventionalist during the intervention procedure. The post processing software also provides for the export of detailed 3D models 124 of the left and/or right atriums inner surfaces. In the case of the left atrium, the four pulmonary veins are clearly defined in 3D models 124. The 3D models 124 include anatomical landmarks that can be used for 3D registration with the coordinate system of the interventional or therapeutic system. The 3D models 124 can be exported in one of several formats: a wire mesh geometric model; a set of contours; a segmented volume of binary images; or a DICOM object using the radiation therapy (RT) DICOM object standard or similar object. Other formats known in the art can also be used to store and export the 3D models 124. Additionally, the operator can view the 3D models 124 on a display screen 122. In another embodiment, the interventional system could contain the advanced 3D registration and/or visualization software included by an embodiment of this invention.

[0019] FIG. 2 is a flow diagram of an exemplary process where image data created on a cardiac CT is used by an interventional planning system. The process begins at step 202 when a volume of data is acquired on the cardiac CT system using a protocol that is optimized for the left and/or right atrium. An example of a protocol that could be used is a coronary artery imaging protocol that uses a helical scan acquisition technique with gated reconstruction. In an exemplary embodiment, parameters used by the coronary artery imaging protocol could include 0.5 second Gantry periods with 0.375 helical pitch factors using single or multi-sector

cardiac reconstruction. Parameters could also include 120 kilovolts, 250 milliamperes, and 1.25 millimeters on a multi-slice CT scanner. At step 204, the image dataset is segmented using post processing software that includes a 3D protocol designed to extract the inner surface of the left and/or right atrium. In an exemplary embodiment, post processing software functions can include applying advanced vessel analysis, depositing seeds, using connectivity, and performing region growing techniques. These functions can be performed with a purchased software tool (e.g., Advanced Vessel Analysis (AVA)). In an exemplary embodiment, after a tool such as AVA is applied to the image dataset, further processing can include: thresholding, floater filtering, scalping, bridging data, and scalping processing. This automated process, at step 204, of segmenting data using a 3D protocol may require one or more queues from the operator. In an exemplary embodiment when a queue is required from the operator the operator may be stepped through the process. The 3D protocol includes default views of the volume and processing steps that can be performed on the data in order to do the 3D segmentation and exporting.

[0020] Next, at step 206, the 3D model is created. The left and/or right atrium is visualized using 3D surface and/or volume rendering including an immersible view. A variety of volume rendering software packages are available including Volume Rendering (VR) and Cardiac Image Quality (CARDIQ). At step 208, the operator identifies three or more specific anatomical landmarks to be used for registration with the interventional system. If rigid registration has been used three anatomical landmarks are required. If nonregistration has been used then more than three anatomical landmarks may be required. In the case of the left atrium, the sinus and two superior pulmonary veins could be used. Landmarks can be visualized in a different color scheme than the inner surface of the heart chamber. Alternatively, explicit geometric markers can be inserted into the volume at the landmarks and the chamber can be visualized in a translucent fashion with opaque geometric landmarks. A volume rendering tool such as the one described previously in reference to step 206 can be used to perform this step. In an exemplary embodiment of the invention the operator will be stepped through the visualization and landmark identification.

[0021] At step 210, specific 3D renderings that are requested for visual reference during the interventional planning procedure are saved. The 3D renderings could be saved in a variety of manners including DICOM images, on film or in a multimedia format. These views could also be blended with the projection image on a fluoroscopy system. A fluoroscopy system can include positioning an x-ray tube on one side of a patient and a detector on the other side of the patient in order to get real time x-ray images. A fluoroscopy system is an example of one way to guide a catheter during a procedure.

[0022] At step 212, a 3D model of the left and/or right atrium is exported using a format of choice. Possible formats include: a wire mesh geometric model; a series of contours; a segmented volume of binary images, and a DICOM object such as the RT DICOM object being used by the radiation therapy DICOM standard. In an exemplary embodiment, all non-relevant data in the binary images are set to zero and the segmented volume of binary images includes only the non-zero information. The value of the voxels correspond to

CT attenuation and the density of a tissue expressed in Hounsfield units makes up the segmented volume of binary images.

[0023] At step 214, the 3D model that has been exported is input to the interventional system. Next, at step 216, the 3D model is registered with the identical landmarks that were identified in step 208. The 3D model can be registered in the coordinate system of the interventional system using rigid or non-rigid registration techniques. At step 218, the model is further visualized on the interventional system and electrical systems are mapped onto the model. The exemplary embodiment described above refers to one 3D model, this could be expanded to any number of 3D models being exported by the cardiac imaging system and imported to the interventional system.

[0024] In another embodiment, the process described in FIG. 2 includes an additional step after the interventional procedure has been completed. This step includes importing into the cardiac imaging system both before and after electrical signals calculated by the interventional system to be displayed and archived in a DICOM format. Additionally, the process described in reference to FIG. 2 is applicable to any chamber (e.g., left or right atrium, left or right ventricle) or vessel (e.g., right coronary artery, ascending aorta) of the heart. Likewise, the process is applicable to ablation or any other type of interventional procedure that requires planning using renderings or 3D models generated by an image acquisition system. The process depicted in FIG. 2 is applicable to other image acquisition systems in addition to a cardiac CT system. For example, if the cardiac images are acquired on a magnetic resonance image (MRI) system, step 204 would include using cardiac segmentation algorithms that are optimized for post processing of magnetic resonance (MR) images.

[0025] FIG. 3 is a flow diagram of an exemplary revised process for performing an interventional procedure using an embodiment of the present invention. The revised process for ablation therapy begins at step 302 with positioning the catheter into the left atrium (LA), guided by the x-ray fluoro. This part of the process typically takes about one hour to perform. Next, at step 304, three or more anatomical landmarks are identified within the atrium using a positioning catheter and the fluoro system in order to define a plane. At step 306, the interventional system performs a 3D registration of the 3D model exported by the cardiac CT system such that the model is transformed into the interventional system coordinate system. Steps 304 and 306 replace part of the current interventional procedure described in the background section. Acquiring a crude 3D geometric representation using 3D positioning information from a special catheter by attempting to sweep through the space of the LA is no longer required. Using steps 304 and 306 instead of the current method allows the interventional procedure to be completed in less time.

[0026] Next, a loop begins that includes steps 308-314. At step 308, electrical information is acquired from one or more heart cycles using a special catheter. The electrical information is mapped onto the detailed geometric model of the atrium using interventional system software. Next, at step 310, the map is visualized to identify the areas of concern that should be treated with ablation. At step 312, heat is administered to create lesions and the software keeps track

of these locations. The electrical map is recollected at step 314 to see the effects of the lesion. This loop, including steps 3084, is repeated as many times as needed to complete the interventional procedure.

[0027] The cardiac CT system for atrial fibrillation planning provides information for planning of interventional procedures so that the interventionalist can avoid acquiring a crude 3D geometric representation of the LA and PV ostiums using a special catheter and sweeping through the space of the LA as described in the background section. This can result in the overall duration of the interventional procedure being reduced. Additionally, with a more detailed 3D geometric representation of the LA and PV's than that which could be acquired by a special catheter, fewer iterations of delivering the therapy, steps 308-314 in FIG. 3, are required. The increased accuracy of the geometry can allow the interventionalist to identify the origins of the problematic electrical signals more quickly and with more precision.

[0028] Although the preceding embodiments are discussed with respect to medical imaging, it is understood that the image acquisition and processing methodology described herein is not limited to medical applications, but may be utilized in non-medical applications.

[0029] As described above, the embodiments of the invention may be embodied in the form of computer-implemented processes and apparatuses for practicing those processes. Embodiments of the invention may also be embodied in the form of computer program code containing instructions embodied in tangible media, such as floppy diskettes, CD-ROMs, hard drives, or any other computer-readable storage medium, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes an apparatus for practicing the invention. An embodiment of the present invention can also be embodied in the form of computer program code, for example, whether stored in a storage medium, loaded into and/or executed by a computer, or transmitted over some transmission medium, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes an apparatus for practicing the invention. When implemented on a general-purpose microprocessor, the computer program code segments configure the microprocessor to create specific logic circuits.

[0030] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another.

1. A method of creating 3D models to be used for cardiac interventional procedure planning, the method comprising:

obtaining acquisition data from a medical imaging system;

creating cardiac image data in response to said acquisition data;

creating a 3D model in response to said cardiac image data;

identifying three anatomical landmarks on said 3D model; and

sending said 3D model to an interventional system, wherein said 3D model is in a format that can be imported and registered with said interventional system.

2. The method of claim 1 further comprising receiving from said interventional system before and after electrical signals calculated by said interventional system.

3. The method of claim 2 further comprising storing said before and after electrical signals in a DICOM format.

4. The method of claim 1 further comprising:

receiving said 3D model at said interventional system;

registering said 3D model on said interventional system, wherein said registering is performed in response to said three anatomical landmarks; and

visualizing said 3D model on said interventional system.

5. The method of claim 1 further comprising:

creating 3D renderings for visual reference in response to said cardiac image data; and

sending said 3D renderings to said interventional system.

6. The method of claim 5 wherein said 3D renderings are blended with a projection image on a fluoroscopy system.

7. The method of claim 1 wherein:

said creating cardiac image data is performed using a tool to step an operator through said creating cardiac image data;

said creating a 3D model is performed using a tool to step an operator through said creating a 3D model; and

said identifying is performed using a tool to step an operator through said identifying.

8. The method of claim 1 wherein said creating cardiac image data includes:

segmenting said acquisition data using post processing software that includes a 3D protocol and instructions for extracting an inner surface of the area of interest; and

visualizing said area of interest including creating an immersible view.

9. The method of claim 8 wherein said post processing software further includes instructions for applying advanced vessel analysis.

10. The method of claim 8 wherein said post processing software further includes instructions for depositing seeds.

11. The method of claim 8 wherein said post processing software further includes instructions for using connectivity, thresholding and morphological operators.

12. The method of claim 8 wherein said post processing software further includes instructions for performing region growing techniques.

13. The method of claim 8 wherein said visualizing is performed in a translucent fashion with opaque geometric landmarks.

14. The method of claim 1 wherein said medical imaging system is a cardiac computed tomography system.

15. The method of claim 1 wherein said medical imaging system is a magnetic resonance imaging system.

16. The method of claim 1 wherein said 3D model is in a wire mesh geometric model format.

17. The method of claim 1 wherein said 3D model is in a series of contours format.

18. The method of claim 1 wherein said 3D model is in a segmented volume of binary images format.

19. The method of claim 1 wherein said 3D model is in a DICOM object format.

20. The method of claim 1 wherein said interventional system is an atrial fibrillation intervention system.

21. The method of claim 20 wherein said atrial fibrillation intervention system is used to perform ablation therapy.

22. A method of creating 3D models to be used for cardiac interventional procedure planning, the method comprising:

receiving acquisition data from a medical imaging system at an interventional system;

creating cardiac image data in response to said acquisition data;

creating a 3D model in response to said cardiac image data;

identifying three anatomical landmarks on said 3D model; and

registering said 3D model on said interventional system, wherein said registering is performed in response to said three anatomical landmarks; and

visualizing said 3D model on said interventional system.

23. The method of claim 22 further comprising creating 3D renderings for visual reference in response to said cardiac image data.

24. A system for creating 3D models to be used for cardiac interventional procedure planning, the system comprising:

a medical imaging system;

an acquisition database in communication with said medical imaging system;

an image database;

a data transfer mechanism; and

a processing device in communication with said data transfer mechanism, said acquisition database and said image database and including instructions to create 3D models to be used for cardiac interventional procedure planning, the method comprising:

obtaining acquisition data from said medical imaging system, wherein said acquisition data is stored in said acquisition database;

creating cardiac image data in response to said acquisition data, wherein said cardiac image data is stored in said image database;

creating a 3D model in response to said cardiac image data;

identifying three anatomical landmarks on said 3D model; and

sending said 3D model to an interventional system, wherein said 3D model is in a format that can be imported and registered with said interventional system and said sending is performed using said data transfer mechanism.

25. The system of claim 24 wherein said processing device includes instructions to implement a method further comprising receiving from said interventional system before and after electrical signals calculated by said interventional system.

26. The system of claim 24 wherein said processing device includes instructions to implement a method further comprising:

creating 3D renderings for visual reference in response to said cardiac image data; and

sending said 3D renderings to said interventional system.

27. The system of claim 24 wherein said acquisition database is relational.

28. The system of claim 24 wherein said image database is relational.

29. The system of claim 24 wherein said medical imaging system includes:

an EKG;

an interface board receiving R-peak event data from said EKG; and

a scanner in communication with said interface board.

30. The system of claim 24 wherein said data transfer mechanism is a network.

31. The system of claim 30 wherein said network is the Internet.

32. The system of claim 24 wherein said medical imaging system is a cardiac computed tomography system.

33. The system of claim 24 wherein said medical imaging system is a magnetic resonance imaging system.

34. The system of claim 24 wherein said interventional system is an atrial fibrillation intervention system.

35. A system for creating 3D models to be used for cardiac interventional procedure planning, the system comprising:

a medical imaging system;

an acquisition database in communication with said medical imaging system;

an image database;

a data transfer mechanism;

an interventional system in communication with said data transfer mechanism; and

a processing device in communication with said data transfer mechanism, said acquisition database and said image database and including instructions to create 3D models to be used for cardiac interventional procedure planning, the method comprising:

obtaining acquisition data from said medical imaging system, wherein said acquisition data is stored in said acquisition database;

creating cardiac image data in response to said acquisition data, wherein said cardiac image data is stored in said image database;

creating a 3D model in response to said cardiac image data;

identifying three anatomical landmarks on said 3D model;

sending said 3D model to said interventional system, wherein said 3D model is in a format that can be imported and registered with said interventional system and said sending is performed using said data transfer mechanism;

receiving said 3D model at said interventional system;

registering said 3D model on said interventional system, wherein said registering is performed in response to said three anatomical landmarks; and

visualizing said 3D model on said interventional system.

36. The system of claim 35 wherein said processing device, said interventional system and said medical imaging system are physically located in the same geographic location.

37. The system of claim 35 wherein said processing device, said interventional system and said medical imaging

system are physically located in more than one geographic location and data is transferred using said data transfer mechanism.

38. A computer program product for creating 3D models to be used for cardiac interventional procedure planning, the product comprising:

a storage medium readable by a processing circuit and storing instructions for execution by the processing circuit for:

obtaining acquisition data from a medical imaging system;

creating cardiac image data in response to said acquisition data;

creating a 3D model in response to said cardiac image data;

identifying three anatomical landmarks on said 3D model; and

sending said 3D model to an interventional system, wherein said 3D model is in a format that can be imported and registered with said interventional system.

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